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# Bulletin No. 106 - A Study of the Production and Movement of Nitric Nitrogen in an Irrigated Soil

Robert Stewart

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# Utah Agricultural College

# EXPERIMENT STATION

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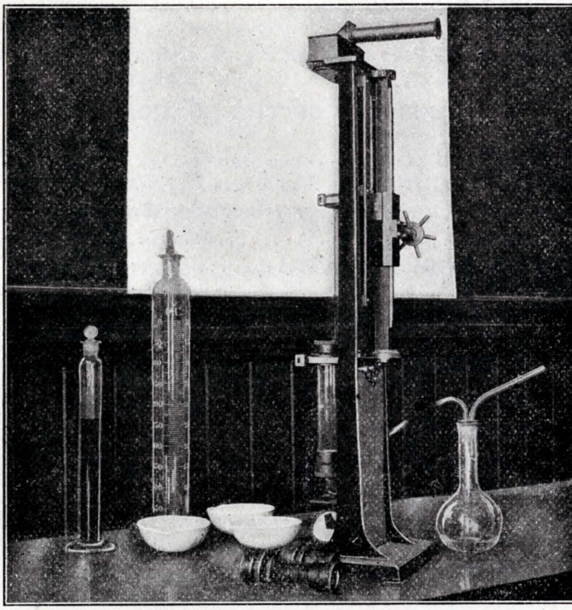

# A STUDY OF THE PRODUCTION AND MOVEMENT

OF

## Nitric Nitrogen in an Irrigated Soil

BY

ROBERT STEWART and J. E. GREAVES

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# The Utah Agricultural Experiment Station



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# A STUDY OF THE PRODUCTION AND MOVEMENT OF NITRIC NITROGEN IN AN IRRIGATED SOIL.

ROBERT STEWART AND JOSEPH E. GREAVES.

## A. INTRODUCTION.

The problem of maintaining the nitrogen content in our agricultural soils is one of vital importance to the development of a permanent system of agriculture. Any investigation, therefore, which tends to throw any light on the conditions which are necessary for maintaining the maximum supply of nitrogen in our soils needs no apology for its institution.

### Importance of the Investigation.

The investigation reported in the following pages was commenced under the direction of Dr. John A. Widtsoe by the senior author of this bulletin, in the summer of 1903, for the purpose of determining the influence of irrigating waters upon the production and movement of nitrates in irrigated soils. The investigation is still being continued. This is the first report and contains the results obtained during the years 1903 to 1907, inclusive. We were led to realize its necessity and to undertake the investigation as a result of a study of the work which was being carried on in the use of irrigating waters, a partial report of which is contained in Bulletin 80 of this Station. It would have been expedient to have carried on simultaneously work in bacteriology, but not having the facilities at that time for doing so, we were forced to content ourselves with the work as reported in the following pages. The work is now being continued in connection with bacteriological investigations.

The excellent work carried on by King, at the Wisconsin Experiment Station, and more recently with the Bureau of Soils, has given us a method for determining the nitric nitrogen contents of the soils. The conditions, however, under which King's work was carried on were quite different from those in the arid west. This fact must be kept in mind in making comparisons of the results obtained by King, with those set forth herein.

### 1. Historical Resume.

The work which has been done on the various phases of nitrification is voluminous and some important facts have been established concerning its processes. Pasteur, as early as 1862, suggested that it was a process brought about by the action of ferments. The work of Lawes and Gilbert[1] is very significant; they found that, as the application of ammonium salts to the land increased, the amount of nitrates in the soil increased; this was indicated by the fact that a few days after a heavy application of ammonium salts there would be a very small amount of ammonia appear in the drainage water, but this soon ceased and nitrates in much larger quantities appeared. There had been many theories advanced to account for this; some of these accounted for the appearance of the nitrates on purely chemical grounds; other theories held that their formation was due to bacterial action. The first experimental proof we have of nitrification being due to bacterial action is that furnished by the work of Schlosing and Muntz[2] in 1879. They passed sewage through tubes filled with earth; the sewage entered rich in ammonia and nitrogenous compounds but the drainage water was much richer in nitrates. Thinking that this change might be due to living organisms, they treated the soil with chloroform and found that the sewage passed through unchanged. Other experiments demonstrated that if the soil be heated, it loses the power of converting ammonia into nitrates.

On the appearance of these facts, the efforts of investigators were directed to the isolation of the organism which could bring about this change. Their work for some time met with little or no success and the workers became divided into two groups; Frank[3] and others claimed that nitrification was

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1 Jour. Chem. Soc. Jan., 1878; Jour. Chem. Soc. July, 1879; Jour. Chem. Soc. Dec., 1884; Jour. Chem. Soc. July, 1891.

2 Compt. rend. 85, 1018. 86-89.

3 Landw. Jahrb (1887).

a purely chemical process, while Warington and Frankland[1] firmly maintained that it was due to bacterial action. The latter isolated special organisms which could change the nitrates into nitrous nitrogen, but not the nitrous into nitric nitrogen. From the work of these men and his own work, Winogradsky[2] decided that the true nitrifying organism would not grow in the ordinary media, so he made media containing inorganic salts, but no organic matter, and by the method of dilution he succeeded, in 1890, in isolating the nitrifying organisms.

We may define nitrification as the converting of ammonium salts into nitrates by bacterial action, the organic nitrogen of the soil first having been converted into ammonia by another class of organisms. So that in the transforming of the organic nitrogen into the nitric nitrogen there are three distinct steps: first, the changing of the organic nitrogen into ammonia; second, the changing of the ammonia thus formed into nitrous nitrogen; and third, the changing of the nitrous nitrogen into nitric nitrogen.

### a. Factors Governing Nitrification.

From the work which has been done in this field we can say almost definitely that there are certain factors which govern the rate of nitrification; but in many cases the details of this control have not been well defined. These controlling factors are: the amount of available plant food in the soil; the reaction, whether acid or alkaline; the temperature; the moisture, and the aeration of the soil. There is a maximum, optimum, and minimum in the above factors, and if we can definitely establish these conditions we will be more fully prepared to understand and govern the processes of nitrification. Knowing how to govern these processes, we would be prepared to plan more intelligently permanent systems of agriculture.

#### 1. Suitable Plant Food.

Higher forms of plant life require certain elements of plant food in order to make a healthy growth—the nitrifying organisms, although lower forms, are no exception to this rule. With the nitrifying organisms this was first shown by

1 Landw. Jahrb (1887), and Landw. Versuchs-Stationen 38, 1888.
2 Experiment Station Record 2, 752-757.

the work of Winogradsky.[1] He studied the nitrifying powers of soils from different parts of the world. In these experiments ammonium sulphate only was added to the soil. From these studies he found that the nitrifying powers of soils from Europe and Asia were low, while the nitrifying powers of soils from America and Africa were high. In other words, the nitrifying powers of a rich soil are high compared with those of poor or depleted soil. Warrington[2] found that if a solution containing ammonium sulphate be seeded with soil containing a nitrifying organism, nitrification will proceed normally —the phosphorus and other essential elements being added with the soil. If from this culture another ammonium sulphate solution be seeded, nitrification will proceed slowly; while if still another be made from the second, there will be little if any nitrification take place.

Fraps,[3] in his work, found that there was a direct relationship existing between the nitrifying powers of a soil and the amount of plant food present, as may be seen from the following summary of his work: "The varying powers of soils to transform organic matter into nitrates under comparable physical conditions were due in part to deficiency in available calcium carbonate, potash or phosphoric acid. Further, a deficiency in phosphoric acid for nitrification is, as a rule, accompanied in the cases under observation by a deficiency in phosphoric acid for corn and cotton."

In the growth of plants it has been found that they suffer just as much from an excess of certain plant elements as from a deficiency. In a general way this appears to be the case with the nitrifying organism in its relationship to organic matter. The nitrogen entering into nitrification is usually indirectly obtained from organic matter. However, it is claimed that an excess of organic matter interferes with nitrifiction. Warrington[4] found that .5 grams of glucose in one thousand c. c. of media retarded the action of the nitrous and nitric organisms and that the processes of nitrification were

1 Archiv. d. Science Biol. St. Petersburg (1892), 87.

2 Bul. 8, Office of Experiment Stations.

3 Experiment Station Record, 16,324.

4 Jour. Chem. Soc. Trans. 1891, 484.

prevented where the glucose reached a concentration of two parts per thousand. This would seem to be almost as effective in stopping the action of nitrifying processes as is carbolic acid on the life processes or ordinary bacteria. Again, he found that if one hundred and fifty parts of ammonia be present, nitrification is prevented. Ammonia is, therefore, praticaly as effective in this case as corrosive sublimate. Nitrates are not found in forest soil to any appreciable extent and this has been attributed to the great amount of organic matter in these soils.

An experiment of A. Muntz,[1] published in 1907, is very interesting in this connection. He made a test of the nitrifying powers of organisms in different media. He used both the organic and inorganic forms of nitrogen. The results of the experiments are summed up as follows: "Humus, even in large quantities, does not interfere with nitrification, but on the other hand is favorable to it. An abundance of humus is not essential to nitrification; but the humus appears to favor the multiplication of the organisms, and a soil which contains a large amount of humus is more abundantly supplied with nitrifying organisms and more apt to enter into rapid nitrification. The idea that organic matter in the soil interferes with nitrification must be abandoned."

### 2. The Reaction of the Soil.

The detrimental effect of organic matter may be due to the formation of organic acids,[2] due to the decay of the organic matter, for the organisms are usually sensitive to acids and alkalies. The amount of acids or alkalies which can be present and not materially interfere with bacterial activities, varies with different classes of organisms. Most forms require a slightly acid media in which to make the best growth. However, the nitrifying bacteria require that the media in which they grow be neutral; or, better still, that it be slightly alkaline. Soils in which there is considerable organic matter will often be assisted in nitrification by adding calcium sulphate. This is due to the fact that when ammonia is formed

1 Experiment Station Record 18, 323.

2 Agricultural Bacteriology, Conn. page 105.

it reacts with the carbonate, forming ammonium carbonate, which leaves the media too strongly alkaline. However, when the calcium sulphate is added it reacts with the ammonium carbonate forming neutral ammonium sulphate, which has little if any effect on the organisms. The acidity of soil is often corrected by adding quicklime but unless the right amount is added there arises an alkaline condition and nitrification is prevented. On the other hand, if calcium carbonate be added, the acidity is corrected, just as well as when the lime is added and, the carbonate being neutral, an excess will do no harm. Further, the corbonate has not the detrimental effect on the organic matter of soil that the lime has.[1]

F. S. Ashly[2] found that nitrification was increased much more when magnesium carbonate was added than when calcium carbonate was added; so on most soils the magnesium carbonate may be used with good effects. It must always be borne in mind, however, that there is danger of getting an excess of this compound, especially if there is a deficiency in the amount of calcium carbonate present; since an excess of this compound acts as a plant poison. Even weak alkali carbonates if present will stop nitrification. This was shown by Schlossing and Muntz.[3] They found that when sodium bicarbonate was present, to the extent of 32 parts in 100,000, nitrification was very materially retarded; and when it reached a concentration of 960 parts in 100,000, very little nitrification took place. Since these experiments, investigations have been carried on at Rothamstead[4] with similar results.

### 3. Temperature.

The temperature is a factor which controls to a certain extent the amount of nitrates formed. Schlossing found that nitrification is very slow at 45 degrees F.; quite marked at 51 degrees, reaches its maximum at 98 degrees, and that it ceased entirely at 131 degrees. These figures are questioned by some investigators, and Warrington[5] states that he was unable to

1 Penn. Sta. Report, 1900, p. 57.

2 Jour. Agr. Science, 2 (1907), 52-67.

3 Compt. rend. 89 L 75.

4 Trans. Chem. Sec. (1884) 653.

5 Office of Experiment Stations, Bul. 8, page 53.

stant nitrification at 104 degrees. King[1] in his work found that there was six times as much nitric nitrogen formed at 90 degrees as there was at 35 degrees, five times as much as at 48 degrees, and nearly twice as much as at 68 degrees. The significance of the figures is brought out more fully when we examine the amount of nitric nitrogen per acre which was formed in 100 days under these varying conditions. At 35 degrees there were formed 120 lbs. per acre; at 48 degrees, 150 lbs. per acre; at 68 degrees, 329 lbs. per acre; while at 90 degrees there were 747 lbs. formed.

#### 4. Soil Moisture.

Another important factor is the amount of moisture. Schlossing[2] found that nitrification increased with the amount of moisture as long as this did not become great enough to interfere with aeration of the soil. He found that a kilogram of soil which contained 9.3 per cent of water produced in a month 157 mg. of nitric acid, while soil containing 20 per cent of moisture produced 470 mg. However, it must not be taken from the above that nitrification increases as the moisture increases. This is true only up to a certain limit. Warrington found that when the percentage of moisture in a soil exceeded this limit the reverse was true, or that denitrification took place.

#### 5. Aeration of Soils.

Nitrification is always best in a well aerated soil, other things being equal. This is brought out in the work by Schlossing[3] where he exposed soil for four months to an atmosphere containing different percentages of oxygen. The soil which contained 1.5 per cent of oxygen yielded 45.7 mg. of nitric nitrogen; that containing 6 per cent of oxygen yielded 95.7 mg.; that containing 11 per cent of oxygen yielded 132.5 mg.; while that containing 16 per cent of oxygen yielded 246.6 mg. of nitric nitrogen. The same amount of soil was used in each case. The work of Deherain[4] shows the effect of stirring the soil and in this way admitting the air into it. He found that

1 Wisconsin Station Bul. 93.
2 Experiment Station Record 26, 359.
3 Compt. rend. 77, 203-353.
4 Compt. rend. 116 (1893), 1094-1097.

soil which had been stirred invariably contained from ten to forty times as much nitric nitrogen per acre as did similar unstirred soil. The work of King[1] also shows that the stirring of the soil affects nitrification. He further found that land plowed in the fall contained a different amount of nitrates than did the unplowed lands. The difference was apparent throughout the following summer.

The crop grown on a soil was found by Ladd[2] to have a marked effect on the nitrates of a soil in succeeding years. He found that on July 14 the field on which corn had been grown the preceeding year contained 39 per cent more nitrates than did the field devoted to continuous wheat culture.

In the Rothamstead experiments it has been shown that about 35 pounds of nitrogen pass off annually in drainage water under average conditions. Some of the factors which control this loss have been learned; as for instance, the growing crop. If a crop can be grown on the soil while nitrification is at its height, a considerable part of the nitrogen which would otherwise be lost can be saved. Again, where irrigation is practiced, the time and amount of water applied may be so arranged as to hold nitrification at its lowest point when the plant does not require the soluble nitrogen.

From the above, it can readily be seen that the control of nitrification is of exceptional importance to Utah agriculture. Therefore, any work which throws light on this important subject is bound to be of great value in helping to establish fundamental principles, as a result of which, more rational and permanent systems of agriculture may be planned in the future.

## B. EXPERIMENTAL PART.

### 1. Location of Experiments ("Greenville Farm").

The investigation was conducted on the "Greenville Farm" belonging to the Experiment Station and located about two miles north of the College farm. The soil of the farm is of a sedimentary nature, being derived from the weathering of lime-stone rocks of the nearby mountain range. At the time of Lake Bonneville the mountain rivers and small

1 Wisconsin Station Report (1901), 210-231.
2 North Dakota Experiment Station Bul. 47.

streams poured their waters, loaded with the weatherings of the lime-stone ridge, in the various stages of subdivision, gravel, sand and silt, into the waters of the lake. When the swiftly running waters of the streams met the quiet waters of the lake, the stream began to deposit its load. The gravel and coarser material being deposited first, gave rise to the well defined deltas found at the mouths of all the larger streams. One of the best defined deltas is that on which the old College farm is located. The fine material consisting mainly of fine sand, silt and clay was carried out farther into the lake, where it was gradually deposited. It is of this sedimentary material that the "Greenville Farm" is composed.

At the beginning of the investigation a soil survey was made of the farm in the following way; samples of soil were taken in foot sections from each plat, the corresponding foot sections of these samples were thoroughly mixed and taken to the chemical laboratory where they were subjected to chemical and physical analysis.

#### a. Chemical Composition of Soils.

Table No. 1 gives the chemical composition of the soil to the depth of 8 feet. The method of analysis followed was that advocated by the Association of Official Agricultural chemists. An examination of the table will show that we have here a soil, like all of our Utah soils, exceptionally rich in the essential plant foods. The potassium is equally as high in the eighth, and intermediate feet, as in the first foot. Both the phosphoric acid and nitrogen are high in the first foot, but gradually decrease in each succeeding foot. The humus, as is characteristic of the soils of arid America, is low. The most important consideration, however, from the view point of this investigation, is the fact that the calcium content of the soil is exceptionally high. Thus one of the conditions for successful nitrification, the presence of a base to neutralize the nitric acid formed, is fulfilled.

#### b. Physical Composition of Soils.

Table No. 2 gives the physical composition of the soil of the "Greenville Farm." The results show the soil to be a

**Table 1—Chemical Composition of the Soil of the Greenville Farm.**

| Depth in Feet. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Insoluble Residue<br>Soluble Silica | 41.46<br>.62 } 42.18 | 35.57<br>.84 } 36.51 | 31.65<br>.41 } 32.16 | 40.90<br>.75 } 41.65 | 28.38<br>0.34 } 28.72 | 29.22<br>0.42 } 29.64 | 30.57<br>0.57 } 31.14 | 30.33<br>0.42 } 30.75 |
| Potash $K_2O$ ............... | 0.67 | 0.89 | 0.59 | 0.82 | 0.61 | 0.74 | 0.79 | 0.75 |
| Soda $Na_2O$ ............... | 0.35 | 0.47 | 0.47 | 0.62 | 0.37 | 0.42 | 0.45 | 0.74 |
| Lime $CaO$ ................. | 16.88 | 17.80 | 21.34 | 15.60 | 22.62 | 23.15 | 22.24 | 21.78 |
| Magnesia $MgO$ ........... | 6.10 | 9.46 | 7.57 | 7.48 | 9.36 | 5.89 | 6.06 | 5.63 |
| Oxide of Iron $Fe_2O_3$ ....... | 3.03 | 2.69 | 3.46 | 2.95 | 2.17 | 2.42 | 2.47 | 2.54 |
| Alumina $Al_2O_3$ ............ | 5.64 | 4.69 | 3.40 | 6.09 | 5.33 | 8.07 | 7.90 | 9.03 |
| Phosphoric Acid $P_2O_5$....... | 0.41 | 0.29 | 0.34 | 0.19 | 0.12 | 0.06 | 0.07 | 0.11 |
| Carbon Dioxide $CO_2$ ....... | 19.83 | 23.11 | 26.67 | 20.88 | 29.31 | 29.57 | 28.80 | 28.13 |
| Volatile Matter ............ | 5.60 | 3.38 | 3.93 | 4.23 | 0.91 | 0.95 | ..... | 0.24 |
| Total .................... | 100.69 | 99.29 | 99.93 | 100.51 | 99.52 | 100.91 | 99.92 | 99.68 |
| | | | | | | | | |
| Humus ..................... | 0.53 | 1.00 | 0.61 | 0.47 | 1.13 | .60 | 0.44 | 0.57 |
| Nitrogen .................... | 0.139 | 0.117 | 0.080 | 0.175 | 0.072 | 0.070 | 0.062 | 0.066 |
| Water at 95 deg. ............ | 1.60 | 1.47 | 1.13 | 1.49 | 0.95 | 1.01 | 1.01 | 0.84 |

**Table 2—Physical Analysis of the Soil of the Greenville Farm.**

| Depth in Feet. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Coarse Sand ................ | 0.21 | 0.17 | 0.68 | 1.02 | 0.09 | 0.34 | 0.47 | 0.09 |
| Medium Sand ............... | 9.63 | 8.29 | 6.63 | 9.63 | 9.53 | 9.48 | 8.91 | 7.08 |
| Fine Sand .................. | 30.04 | 32.54 | 29.49 | 33.06 | 36.92 | 33.79 | 35.34 | 34.25 |
| Coarse Silt ................ | 32.25 | 32.81 | 32.62 | 28.51 | 28.65 | 30.49 | 31.65 | 32.65 |
| Medium Silt ............... | 12.30 | 10.46 | 10.89 | 10.95 | 10.46 | 10.85 | 9.92 | 9.89 |
| Fine Silt ................... | 6.25 | 4.81 | 7.27 | 6.94 | 4.85 | 5.86 | 5.56 | 5.84 |
| Clay ........................ | 7.62 | 7.12 | 10.13 | 7.52 | 7.82 | 6.78 | 6.52 | 7.57 |
| Moisture ................... | 1.60 | 1.47 | 1.13 | 1.49 | 0.95 | 1.01 | 1.01 | 0.84 |
| Soluble and Lost ............ | 0.10 | 2.33 | 1.16 | 0.83 | 0.73 | 1.40 | 1.42 | 1.99 |
| | | | | | | | | |
| Specific Gravity ............ | 2.67 | 2.72 | 2.80 | 2.69 | 2.76 | 2.79 | 2.71 | 2.76 |
| Apparent Specific Gravity ... | 1.23 | 1.27 | 1.30 | 1.29 | 1.33 | 1.34 | 1.39 | 1.35 |
| Water Soluble Salts ........ | .06 | .11 | .14 | .16 | .08 | .09 | .15 | .09 |

good loam of remarkable uniformity throughout the eight feet.

### 2. Method of Taking Soil Samples.

In every case, except the first year of the experiment, samples of soils were taken in foot sections to a depth of 10 feet, by means of ordinary wood augers. During the first two years three borings were made on each plat. These three borings were used to form a composite sample which was subjected to analysis. During the last two years single samples were taken from as near the center of the plat as possible, care being taken that separate borings were at least three feet apart. The samples thus obtained were taken to the chemical laboratory where a portion of the moist sample was used for nitric nitrogen determination while a second portion was taken for moisture determination. The results reported here, therefore, are all referred to moisture-free basis.

### 3. Method of Analysis.

The method of obtaining the soil extract and determining the nitric nitrogen is essentially that of King. The only change made was in using one-half as much potassium alum crystals, as we could thus obtain a clearer solution. When we used the amount recommended by King, we obtained a cloudy solution which had to be filtered before the comparison with the standard could be made.

#### a. Influence of Chlorides.

Inasmuch as the sensitiveness of the method is affected by chlorides it was thought desirable to make a determination of the chlorides in the soil solution. It was also decided to determine the greatest amount of chlorides which could be present in the soil extract and still not affect the sensitiveness of the method. The chlorides in the soil solution were determined as follows: 50 c. c. of the soil solution prepared as for nitric nitrogen determination was titrated against one hundred normal silver nitrate solution. The results obtained are given in Table 3.

### Table No. 3.
### THE AMOUNT OF CHLORIDES PRESENT IN THE SOIL EXTRACT.
**(Results Expressed in Terms of Sodium Chloride and as Parts per Million.)**

| No. of | Depth in Feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Plot.. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 41G .. | 1.17 | 1.17 | .819 | 2.457 | 1.053 | 1.521 | 1.521 | 1.287 | 1.638 | .703 |
| *41G .. | 1.638 | 1.521 | .819 | .585 | .819 | 1.053 | .936 | .936 | 1.053 | .936 |
| 42G .. | 1.287 | .936 | 1.17 | 1.287 | 1.404 | .819 | .819 | .819 | 1.404 | .819 |
| *42G .. | 1.638 | 1.638 | 1.053 | .819 | 1.053 | 1.17 | 1.053 | 1.17 | .819 | .819 |
| 43G .. | 1.287 | .702 | 1.521 | 1.17 | 1.872 | .819 | 1.521 | .819 | .702 | .702 |

*Taken from wettest part of plot.

It will be seen from the above table that in no case do the chlorides exceed 2.5 parts per million. Having learned the maximum amount of chlorides occuring in our soil solutions, it then becomes necessary to learn the greatest amount of chlorides which may be present and not affect the sensitiveness of the method. With this object in view known amounts of sodium chloride were added to 1 c. c. of the standard potassium nitrate solution which was evaporated to dryness and then treated as in the nitric nitrogen determination of the soil. The solutions thus obtained were compared with a standard solution of potassium nitrate obtained in the usual manner.

### Table No. 4.
### THE EFFECT OF THE CHLORIDES ON THE SENSITIVENESS OF THE METHOD.
**(Results Expressed as Parts per Million.)**

| Sodium Chloride Added | Nitric Nitrogen Present | Nitric Nitrogen Found | Sodium Chloride Added | Nitric Nitrogen Present | Nitric Nitrogen Found |
|---|---|---|---|---|---|
| .871 | .1 | .1 | 8.71 | .1 | .1 |
| 1.742 | .1 | .1 | 9.581 | .1 | .095 |
| 2.613 | .1 | .1 | 10.452 | .1 | .094 |
| 3.484 | .1 | .1 | 11.313 | .1 | .092 |
| 4.355 | .1 | .095 | 12.149 | .1 | .092 |
| 5.226 | .1 | .090 | 13.065 | .1 | .092 |
| 6.097 | .1 | .098 | 13.936 | .1 | .092 |
| 6.968 | .1 | .090 | 14.807 | .1 | .090 |
| 7.839 | .1 | .090 | 15.678 | .1 | .086 |

It will be seen from the above table that the method was not affected by the presence of chlorides until a concentration of approximately four parts per million was reached, after which the chloride solution seemed to show less nitric nitrogen than was really present. Since the maximum amount of sodium chloride found in our soil solution was only 2.5 parts per million, it appears that we are justified in saying that the accuracy of the method is not affected by the amount of chlorides present.

#### b. Composition of Irrigating Water.

The water which was applied to the plots in the following experiments, was clear and of exceptional purity; but in order to determine to what extent the results would be affected by the nitric nitrogen in the water, samples were collected at intervals during the irrigating season and tested for nitric nitrogen. The following table shows the amount of nitric nitrogen in the irrigating water expressed in parts per million, and also the amount of nitric nitrogen which would be added to the soil by the application of five and ten inches of irrigating water. In the calculation of the results a cubic foot of water was regarded as weighing 62.5 pounds.

### Table No. 5.
### THE NITRIC NITROGEN CONTENTS OF IRRIGATING WATERS.

| Date of Analysis | Parts of Nitric Nitrogen Per Million | Pounds Per Acre | | Date of Analysis | Parts of Nitric Nitrogen Per Million | Pounds Per Acre | |
|---|---|---|---|---|---|---|---|
| | | 5-inch Irrig. | 10-inch Irrig. | | | 5-inch Irrig. | 10-inch Irrig. |
| June 29 | .800 | .9178 | 1.8356 | July 31 | .650 | .7455 | 1.4910 |
| July 2 | .800 | .9178 | 1.8356 | Aug. 4 | .550 | .6308 | 1.2616 |
| July 6 | .400 | .4589 | .9178 | Aug. 4 | .500 | .5736 | 1.1427 |
| July 10 | 1.000 | 1.1472 | 2.344 | Aug. 9 | .350 | .4016 | .8032 |
| July 13 | .7415 | .8505 | 1.601 | Aug. 11 | .500 | .5736 | 1.4472 |
| July 26 | .6600 | .7572 | 1.514 | Aug. 18 | .305 | .3663 | .7326 |
| July 28 | .650 | .7455 | 1.491 | Aug. 18 | .275 | .3162 | .6324 |

It will be seen from the above table that the results were affected very slightly by the water applied; an application of ten inches of water increased the nitric nitrogen in one acre less than two pounds.

## 4. PRELIMINARY WORK OF 1903.

### a. Method of Stating Results.

The results in this bulletin are reported as pounds per acre of the element nitrogen which existed in the form of a nitrate at the time of sampling. In every case the computations have been made on the dry basis. The weight of one acre foot of soil has been taken as three million six hundred thousand pounds.

### b. Work With Various Crops.

The work was commenced in 1903 and was conducted on fourteen plots devoted to the growing of alfalfa, sugar beets, potatoes and oats. Most of the work, however, was done with the three oat plots. During this year we took samples to a depth of only four feet. Our work with the oat plots brought out two important facts: first, samples of soil were not taken deep enough; second, the concentration of nitric nitrogen of the soil during the last few weeks of the life of the oat plant decreased materially. It was noticed that for two weeks before harvesting the crop on August 10th, the nitrate content of the soil rapidly decreased. The nitrate content of the plots during the early part of July was high; the concentration began decreasing about July 18th and continued to decrease until time of harvesting on August 10th, after which it slowly increased.

Work was also carried on during this season on three sugar beet plots. These plots were sampled fifteen times during July, August, September and October to a depth of four feet. No apparenut regularity could be observed in a study of the results and the only noteworthy fact brought out was that the soil showed a high nitrate content througout the year. The lowest amount of nitric nitrogen present was higher than the maximum amount in the soil on which oats were growing.

Three plots on which corn was growing were also utilized for nitrate work. These plots were sampled five times to a depth of four feet during July, August, September and October. Again no aparent regularity was observed. The total nitric nitrogen content varied from 21 pounds per acre to 151 pounds per acre. There was a tendency for the nitric nitrogen to accumulate in the first foot during the latter part of the season.

Two corn plots were sampled five times during the season. Large amounts of nitric nitrogen were observed throughout the season in each foot section.

Samples were taken twice during the season from two plots which had been planted to alfalfa the previous year. The important fact noticed was that the alfalfa plant makes heavy demands on the nitric nitrogen content of the soil.. In no case did the nitrogen content rise above 50 pounds per acre, while most of the time it was very much less.

#### c. Conclusions for Season.

Very little definite information was obtained during the first year's work. This was due to a certain extent to the failure to take the samples to a sufficient depth. The following were the principal facts learned: (a) the irrigating water carried the soluble nitrates to a greater depth than four feet; (b) the oat plant made heavy demands upon the nitric nitrogen of the soil; (c) the nitric nitrogen content of corn and sugar beet land was comparatively high while the nitric nitrogen content of alfalfa land remained low throughout the year.

### 5. WORK SINCE THE SEASON OF 1903.

### (1904 to 1907 Inclusive.)

#### a. General Outline of Work.

During the seasons from 1904 to 1907 inclusive, five thousand seven hundred and forty samples of soil were tested for nitric nitrogen. The results reported in the following tables are always an average of a number of determinations. For this reason the error due to individual soil samples is largely eliminated and the results reported are strictly comparable. The crops grown were corn, potatoes and alfalfa. Samples were also taken from fallow land. The cropped irrigated plots received a maximum, medium and minimum amount of water. These terms as used in this discussion are indicative of variable quantities, depending upon the crop and season. The maximum amount of water for the season has been taken as the highest amount which would be applied to a given crop during the season under consideration, or in other words, the application of the greatest amount of water possible without materially harming the crop. The medium amount of water is taken as the best amount of water to apply to a given crop during the season under consideration. The minimum amount of irrigation water is taken as the least amount of water that, in actual irrigation practice, is applied to a given crop during the season under consideraion.

In the following discussion, for convenience, the growing season is divided into three periods: (a) the spring period, which includes the time from the taking of the first samples in the early spring to the first application of irrigating water to the plot; (b) the irrigating period; (c) the fall period, which includes the time from the last application of irrigating water to the taking of the last samples in the late fall.

### b. Maximum Amount of Water.

Some very important results are shown in Tables 6, 7, 8 and 9. In the corn land, before the irrigating period commenced there was a high content of nitric nitrogen with the greatest concentration in the 1st, 2nd and 5th foot sections. During the irrigating period there was still a high content of nitrogen, but the application of the irrigating water caused a decrease. The greatest decrease was in the surface feet, with an increase in the 10th foot. This is undoubtedly due, in part at least, to the irrigating water in carrying the nitrogen to lower depths. This idea is supported by a study of the moisture results in Table 10, wherein it may be seen that the moisture content has increased in the 10th foot, thus indicating that the soluble nitrates may have been carried to great depths.

During the fall period there is a marked decrease in the nitric nitrogen content of corn land. It is noticeable that the nitric nitrogen content of the surface feet is lower than at any other period.

In the case of the pototo land before the commencement of the irrigating period there was a medium content of nitric nitrogen. There was a decrease in the nitrogen content throughout the ten feet during the irrigating period.

There was a marked decrease in the nitrogen content of potato land during the fall period, which is noticed in each foot section.

**TABLE 6. DEVELOPMENT AND MOVEMENT OF NITRIC NITROGEN OF THE SOIL DURING THE SPRING PERIOD.**

| Per Cent. Moisture | No of Det | PER CENT MOISTURE. | | | | | | | | | | NITRIC NITROGEN (N) POUNDS PER ACRE. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth in Feet.... | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | To't. |
| MAXIMUM. | | | | | | | | | | | | | | | | | | | | | | |
| Corn ............ | 10 | 13.89 | 14.31 | 15.08 | 14.31 | 13.94 | 14.37 | 13.95 | 13.01 | 11.37 | 11.05 | 24.5 | 22.7 | 12.8 | 12.9 | 34.5 | 9.2 | 13.2 | 12.3 | 8.5 | 11.8 | 162.4 |
| Potato ............ | 9 | 14.63 | 13.75 | 13.62 | 12.95 | 12.81 | 11.41 | 12.03 | 11.78 | 11.23 | 10.93 | 10.7 | 7.1 | 5.7 | 4.0 | 7.3 | 7.6 | 6.0 | 6.0 | 6.4 | 4.9 | 65.7 |
| Alfalfa ............ | 14 | 15.66 | 15.03 | 15.16 | 15.13 | 14.32 | 15.24 | 14.05 | 13.00 | 13.06 | 12.41 | 2.8 | 7.1 | 5.1 | 3.2 | 4.0 | 5.3 | 4.6 | 4.1 | 3.2 | 4.2 | 43.6 |
| Fallow .......... | | | | | | | | | | | | | | | | | | | | | | |
| MEDIUM. | | | | | | | | | | | | | | | | | | | | | | |
| Corn .............. | 10 | 13.85 | 13.95 | 14.49 | 14.07 | 13.08 | 14.09 | 14.24 | 12.67 | 11.35 | 10.97 | 28.2 | 24.2 | 15.2 | 14.2 | 17.2 | 26.6 | 12.9 | 10.9 | 7.2 | 6.0 | 162.6 |
| Potato .......... | 9 | 13.5 | 13.71 | 14.05 | 13.67 | 13.11 | 12.18 | 12.07 | 11.41 | 11.97 | 11.12 | 30.0 | 14.0 | 7.2 | 8.2 | 15.0 | 12.5 | 11.7 | 11.1 | 6.7 | 6.0 | 122.4 |
| Alfalfa ........... | 2 | 15.06 | 12.73 | 14.51 | 14.20 | 14.43 | 15.21 | 15.09 | 11.60 | 10.33 | 11.31 | 4.2 | 2.7 | 3.1 | 6.4 | 1.4 | 1.4 | 1.3 | 1.3 | 1.4 | 2.4 | 25.6 |
| Fallow ............ | 12 | 14.24 | 14.44 | 15.82 | 14.74 | 14.94 | 12.82 | 11.58 | 10.76 | 10.81 | 11.08 | 16.1 | 30.1 | 11.0 | 5.6 | 8.6 | 9.7 | 10.7 | 18.2 | 21.0 | 5.0 | 136.0 |
| MINIMUM. | | | | | | | | | | | | | | | | | | | | | | |
| Corn ............. | 2 | 14.73 | 13.92 | 13.82 | 14.66 | 13.32 | 14.96 | 13.69 | 12.87 | 11.47 | 10.93 | 14.5 | 22.2 | 18.3 | 11.1 | 7.1 | 10.2 | 4.7 | 4.2 | 5.1 | 5.7 | 10.31 |
| Potato ........... | 5 | 13.7 | 13.08 | 13.46 | 14.25 | 13.65 | 13.60 | 11.92 | 11.96 | 11.98 | 12.55 | 12.7 | 14.8 | 4.8 | 3.9 | 5.4 | 10.1 | 6.4 | 6.3 | 5.2 | 1.7 | 71.3 |
| Alfalfa .......... | 2 | 14.31 | 12.83 | 13.62 | 13.85 | 14.18 | 13.28 | 14.47 | 13.41 | 10.29 | 10.15 | 2.0 | 3.3 | 1.3 | 2.8 | 1.1 | 0.8 | 9.1 | 23.7 | 22.6 | 21.3 | 88.0 |
| NONE. | | | | | | | | | | | | | | | | | | | | | | |
| Corn ............. | 10 | 14.29 | 14.20 | 14.34 | 14.05 | 13.69 | 14.33 | 13.27 | 13.32 | 12.09 | 11.51 | 21.8 | 14.3 | 8.0 | 5.2 | 8.4 | 15.0 | 16.8 | 15.0 | 14.0 | 17.4 | 135.9 |
| Potato ........... | 9 | 14.94 | 14.30 | 14.51 | 13.84 | 13.43 | 12.77 | 11.70 | 11.81 | 11.84 | 11.73 | 16.5 | 12.9 | 6.4 | 9.5 | 7.7 | 12.6 | 11.0 | 27.0 | 9.5 | 13.0 | 126.1 |
| Alfalfa .......... | 2 | 13.16 | 12.43 | 13.82 | 13.84 | 12.3 | 10.31 | 14.09 | 12.85 | 10.19 | 10.61 | 3.5 | 2.7 | 17.1 | 3.4 | 2.7 | 2.8 | 2.4 | 10.0 | 4.1 | 15.1 | 63.8 |
| Fallow .......... | 6 | 15.76 | 14.98 | 15.61 | 15.43 | 14.81 | 15.29 | 13.85 | 11.46 | 10.94 | 12.45 | 29.5 | 24.0 | 5.3 | 7.0 | 7.2 | 10.7 | 10.0 | 6.0 | 5.0 | 8.0 | 112.7 |

There was a nitric nitrogen content of forty-three pounds in the alfalfa land at the close of the spring period. The application of irrigating water caused a slight decrease but it thereafter remained practically constant throughout the year.

### c. Medium Amount of Water.

There is a high nitric nitrogen content in corn land during the spring period. The application of irrigating water caused a decrease. However, it is noticeable that the application of irrigating water caused an increase of nitric nitrogen in the first and second feet. It is noteworthy that the decrease which was observed in the nitric nitrogen during the irrigating period was not as great as where the maximum amount of water had been applied. However, exactly the reverse is true during the fall period. The loss in corn land receiving the maximum application of irrigating water was twenty pounds while in the land receiving the medium application the loss was seventy pounds.

There was a high content of nitric nitrogen in potato land during the spring period; it was especially high in the first and second feet. The application of irrigating water caused a decrease of nitric nitrogen which extends throughout the ten feet. The water applied had probably penetrated to a greater depth than ten feet as is shown by a study of the moisture content in Table 10. There was a decrease in the nitrogen content during the fall period.

There was again a higher content of nitric nitrogen in the alfalfa land during the spring period with a lower and almost constant content throughout the remainder of the year.

In the fallow land there was a high nitric nitrogen content during the spring. It became concentrated in the first foot during the summer months. On the application of irrigating water there was a decrease in the total nitric nitrogen content. The nitric nitrogen content was high during the fall period which was exactly the opposite from that which was found to be true with all the other plots receiving a medium amount of water.

### d. Minimum Amount of Water.

There was a high nitrogen content in the corn land during the spring period. The application of irrigating water

**TABLE 7. DEVELOPMENT AND MOVEMENT OF NITRIC NITROGEN OF THE SOIL BEFORE AND AFTER IRRIGATION, DURING THE IRRIGATING PERIOD. RESULTS EXPRESSED AS POUNDS PER ACRE.**

| Crop | No. of Det. | BEFORE IRRIGATION. | | | | | | | | | | | AFTER IRRIGATION. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth in Feet........ | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Tot'l. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Tot'l. |
| MAXIMUM | | | | | | | | | | | | | | | | | | | | | | | |
| Corn | 16 | 18.8 | 10.6 | 9.0 | 10.7 | 20.4 | 9.1 | 9.7 | 15.1 | 12.9 | 9.6 | 125.9 | 8.7 | 8.8 | 4.8 | 4.7 | 7.3 | 9.0 | 10.7 | 19.5 | 10.7 | 19.1 | 93.3 |
| Potato | 15 | 10.7 | 5.7 | 4.5 | 5.5 | 7.1 | 5.9 | 9.6 | 9.0 | 7.8 | 7.5 | 73.3 | 7.1 | 5.4 | 4.9 | 4.7 | 3.8 | 5.5 | 5.7 | 4.5 | 7.8 | 5.7 | 55.1 |
| Alfalfa | 35 | 3.2 | 6.0 | 4.9 | 1.9 | 3.3 | 2.1 | 3.9 | 1.8 | 1.7 | 2.3 | 31.1 | 6.3 | 2.5 | 4.0 | 2.4 | 5.1 | 3.1 | 2.8 | 1.6 | 4.5 | 1.8 | 34.1 |
| Fallow. | | | | | | | | | | | | | | | | | | | | | | | |
| MEDIUM. | | | | | | | | | | | | | | | | | | | | | | | |
| Corn | 13 | 17.4 | 11.3 | 16.1 | 22.1 | 16.3 | 17.9 | 13.4 | 20.7 | 10.5 | 8.2 | 153.9 | 24.4 | 18.3 | 9.2 | 8.5 | 10.0 | 10.7 | 13.0 | 8.7 | 8.6 | 7.5 | 118.9 |
| Potato | 12 | 17.1 | 11.3 | 6.2 | 6.0 | 8.9 | 9.0 | 14.4 | 14.1 | 11.1 | 7.4 | 105.5 | 9.4 | 8.0 | 9.8 | 5.8 | 2.0 | 6.8 | 10.2 | 11.7 | 7.9 | 5.5 | 82.1 |
| Alfalfa | 5 | 4.0 | 1.9 | 1.8 | 1.2 | 1.2 | 3.1 | 0.9 | 3.0 | 1.2 | 2.2 | 20.5 | 1.9 | 1.5 | 1.5 | 2.1 | 1.6 | 1.6 | 1.2 | 1.3 | 1.3 | 2.0 | 16.0 |
| Fallow | 12 | 19.8 | 22.8 | 16.5 | 10.2 | 10.5 | 9.0 | 12.0 | 14.3 | 12.3 | 14.8 | 142.2 | 11.2 | 13.7 | 19.1 | 13.9 | 11.1 | 9.4 | 15.5 | 13.2 | 9.1 | 13.0 | 129.2 |
| MINIMUM. | | | | | | | | | | | | | | | | | | | | | | | |
| Corn | 2 | 15.9 | 18.8 | 8.1 | 4.2 | 5.9 | 13.2 | 6.9 | 5.2 | 4.1 | 5.7 | 88.0 | 13.1 | 10.7 | 5.9 | 5.8 | 7.5 | 7.8 | 4.9 | 3.1 | 2.4 | 4.0 | 65.2 |
| Potato | 3 | 27.3 | 26.0 | 8.0 | 4.8 | 5.8 | 9.1 | 10.7 | 10.7 | 5.0 | 2.8 | 110.2 | 20.1 | 18.2 | 7.0 | 7.8 | 8.5 | 6.7 | 5.0 | 5.3 | 4.0 | 2.1 | 84.7 |
| Alfalfa | 5 | 2.9 | 2.1 | 1.3 | 1.0 | 1.3 | 1.2 | 1.3 | 2.8 | 9.9 | 9.8 | 33.6 | 4.9 | 2.3 | 1.8 | 1.3 | 1.2 | 1.2 | 1.1 | 2.7 | 8.5 | 7.6 | 32.6 |
| Fallow | | | | | | | | | | | | | | | | | | | | | | | |
| NONE. | | | | | | | | | | | | | | | | | | | | | | | |
| Corn | 18 | 26.7 | 17.1 | 6.7 | 6.4 | 14.4 | 22.5 | 24.0 | 20.5 | 15.1 | 16.8 | 170.2 | 24.9 | 17.2 | 7.6 | 6.0 | 16.0 | 23.3 | 25.6 | 24.6 | 16.9 | 16.1 | 178.2 |
| Potato | 14 | 32.0 | 15.5 | 11.4 | 9.1 | 11.0 | 9.2 | 11.1 | 18.0 | 11.8 | 12.9 | 142.0 | 32.4 | 13.2 | 9.4 | 8.5 | 9.6 | 8.2 | 10.5 | 15.3 | 11.6 | 10.6 | 129.3 |
| Alfalfa | 7 | 2.9 | 1.7 | 1.5 | 1.3 | 1.4 | 1.3 | 1.4 | 3.6 | 6.3 | 7.9 | 29.3 | 2.3 | 1.7 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 2.7 | 5.1 | 7.7 | 26.1 |
| Fallow | 18 | 20.4 | 14.2 | 8.5 | 5.5 | 8.4 | 13.4 | 10.6 | 9.5 | 8.0 | 8.1 | 106.6 | 20.4 | 14.2 | 8.4 | 5.5 | 8.5 | 13.5 | 10.6 | 9.5 | 8.0 | 8.1 | 106.7 |

caused a slight decrease in the total nitric nitrogen content which can also be noticed in each foot section. There was a decrease in nitric nitrogen during the fall period.

In the potato land there was a medium amount of nitric nitrogen during the spring period. On the application of irrigating water there was a decrease. There was still a further decrease during the fall period. This decrease is noticeable mainly in the surface feet. In alfalfa land there was a very high content in the spring period which decreased slightly throughout the remainder of the year.

#### e. Unirrigated Land.

The nitrogen in the corn land during the spring months was high but reached a maximum during the summer months, followed by a marked decrease during the fall period. An examination of the individual feet supports this statement to a marked degree, showing that a portion of the increase at least comes from below the tenth foot.

The nitric nitrogen content in the potato land was high in the spring, while there was a very slight increase during the summer months and no appreciable change during the fall period.

The nitrogen content of alfalfa land was low during the spring period with a slight decrease during the summer months; it remained practically constant throughout the remainder of the year.

The nitric nitrogen content of fallow land was high during the spring and remained nearly constant throughout the remainder of the year. The nitric nitrogen content of these plots was high during the summer months and remained practically constant during the fall. This is a fact which was observed with the unirrigated potato land and also with the fallow land, both irrigated and unirrigated, while in the case of all the other plots there was a marked decrease during the fall months.

#### f. Influence of Crop.

On considering the land with the different crops we find that certain definite relationships appear. The greatest nitric nitrogen content was in the soil of the unirrigated corn land during the summer season. The next greatest was that

**TABLE 8. PERCENTAGE OF MOISTURE IN THE SOIL BOTH BEFORE AND AFTER IRRIGATION, DURING IRRIGATING PERIOD.**

| Crop | | BEFORE IRRIGATION. | | | | | | | | | | AFTER IRRIGATION. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth in Feet.. | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| MAXIMUM. | | | | | | | | | | | | | | | | | | | | | |
| Corn . ......... | 15 | 12.03 | 12.50 | 14.04 | 14.16 | 13.77 | 14.64 | 14.48 | 13.16 | 11.15 | 11.21 | 18.01 | 16.73 | 16.64 | 16.33 | 15.25 | 15.84 | 15.29 | 14.00 | 12.53 | 12.25 |
| Potato . ....... | 14 | 13.05 | 12.82 | 13.76 | 13.77 | 13.73 | 13.84 | 13.86 | 13.05 | 12.88 | 12.64 | 21.02 | 19.62 | 18.73 | 17.42 | 14.89 | 15.02 | 14.38 | 14.08 | 13.28 | 12.54 |
| Alfalfa . ....... | 30 | 13.98 | 14.30 | 15.00 | 15.22 | 14.41 | 15.37 | 15.17 | 13.93 | 13.38 | 13.39 | 19.18 | 18.59 | 18.67 | 17.98 | 16.79 | 16.71 | 16.54 | 15.20 | 13.97 | 13.80 |
| Fallow . ....... | | | | | | | | | | | | | | | | | | | | | |
| MEDIUM. | | | | | | | | | | | | | | | | | | | | | |
| Corn . .......... | 13 | 11.58 | 12.27 | 13.07 | 13.21 | 12.95 | 14.15 | 13.36 | 12.91 | 11.44 | 10.92 | 16.62 | 14.81 | 14.31 | 13.97 | 13.05 | 14.49 | 13.79 | 13.04 | 11.85 | 11.16 |
| Potato . ........ | 11 | 11.39 | 11.58 | 12.61 | 13.18 | 13.06 | 12.48 | 12.66 | 12.48 | 12.42 | 11.76 | 19.06 | 17.14 | 15.56 | 14.81 | 14.13 | 14.11 | 14.09 | 13.63 | 13.32 | 12.46 |
| Alfalfa . ........ | 5 | 11.20 | 11.76 | 13.46 | 13.45 | 13.16 | 14.23 | 14.35 | 11.20 | 9.80 | 11.26 | 19.45 | 17.20 | 16.81 | 15.88 | 14.58 | 15.48 | 15.04 | 11.66 | 9.58 | 10.60 |
| Fallow . ........ | 12 | 12.39 | 13.28 | 15.44 | 14.32 | 14.33 | 12.56 | 11.18 | 11.03 | 10.69 | 11.21 | 19.77 | 19.01 | 19.05 | 16.03 | 16.01 | 14.41 | 12.65 | 12.35 | 11.92 | 12.04 |
| MINIMUM. | | | | | | | | | | | | | | | | | | | | | |
| Corn . .......... | 2 | 10.55 | 10.54 | 10.72 | 12.44 | 11.80 | 13.87 | 12.73 | 12.07 | 11.25 | 10.62 | 19.89 | 15.39 | 10.65 | 11.42 | 11.97 | 14.00 | 13.09 | 12.85 | 11.88 | 9.92 |
| Potato . ........ | 3 | 8.76 | 9.89 | 11.59 | 13.49 | 12.68 | 13.02 | 12.00 | 11.66 | 12.32 | 12.49 | 13.50 | 10.56 | 9.42 | 9.06 | 8.61 | 9.18 | 7.97 | 8.31 | 8.41 | 12.23 |
| Alfalfa . ........ | 5 | 11.25 | 10.89 | 12.14 | 12.89 | 12.60 | 11.94 | 12.88 | 13.09 | 10.16 | 10.49 | 17.76 | 13.56 | 12.92 | 12.76 | 13.05 | 12.36 | 12.40 | 13.86 | .98 | 13.28 |
| Fallow . ....... | | | | | | | | | | | | | | | | | | | | | |
| NONE. | | | | | | | | | | | | | | | | | | | | | |
| Corn . .......... | 18 | 8.05 | 9.21 | 9.34 | 10.44 | 11.51 | 12.36 | 12.03 | 12.18 | 11.27 | 10.68 | 8.20 | 9.08 | 9.35 | 10.40 | 11.55 | 12.16 | 12.16 | 12.29 | 11.35 | 10.83 |
| Potato . ........ | 17 | 9.24 | 9.99 | 11.37 | 11.27 | 11.13 | 11.03 | 10.33 | 10.74 | 11.43 | 11.68 | 9.27 | 9.56 | 10.85 | 10.24 | 10.98 | 10.57 | 10.21 | 10.71 | 11.60 | 11.76 |
| Alfalfa . ....... | 7 | 7.06 | 7.67 | 8.77 | 9.51 | 8.87 | 8.14 | 9.91 | 11.11 | 9.81 | 10.22 | 6.82 | 7.47 | 8.80 | 9.44 | 8.51 | 8.03 | 9.79 | 11.14 | 9.61 | 9.86 |
| Fallow . ........ | 18 | 11.16 | 12.46 | 13.40 | 13.62 | 13.99 | 14.28 | 12.33 | 11.03 | 10.40 | 12.54 | 11.15 | 12.46 | 13.04 | 13.62 | 13.99 | 14.28 | 12.33 | 11.04 | 10.40 | 12.54 |

receiving the medium amount of water. The unirrigated plots were more concentrated in the first feet that the plots which received water. The former had a greater concentration of nitric nitrogen in the ninth and tenth feet than the irrigated plots thus tending to show that part of the nitric nitrogen came from lower depths.

**Corn.** In the fall the nitric nitrogen of the soil of the unirrigated plot was not as high as that of the plot receiving the maximum irrigation. There had been a loss of 105 pounds from the unirrigated plot and twenty pounds from the plot receiving the maximum irrigation during the fall period. The greatest decrease was in the lower depths.

The amount of nitric nitrogen of the soil both before and after irrigation during the irrigating period was inversely proportional to the water applied.

The nitric nitrogen content of the soil was lower after irrigation than before but this may be due to other factors than the application of the water since the decrease in the unirrigated plot was fully as great. With the irrigated plots the greatest loss was from the surface feet while from the unirrigated plot the loss was greatest in the lower depths.

**Alfalfa.** The nitric nitrogen was highest during the spring and lowest during the fall with an intermediate amount during the irrigating period.

**Fallow.** The total nitric nitrogen in the ten feet remained the highest throughout the year in the plots receiving the medium amount of water. However, the nitrogen became more concentrated in the surface feet than did the irrigated soil.

The nitric nitrogen of corn, potatoes and fallow land was high in spring and summer, except in the case of fallow and the unirrigated plots, comparatively low in the fall. The nitric nitrogen in alfalfa land was low throughout the year.

The application of water to corn, potatoes and fallow land caused a decrease in the total nitric nitrogen. This was due in part to the carrying of it to lower depths as was indicated by the increase in the soil moisture of the lower foot sections.

**TABLE 9. DEVELOPMENT AND MOVEMENT OF NITRIC NITROGEN OF SOIL DURING THE FALL PERIOD.**

| Crop | No. of Det. | PERCENT MOISTURE. | | | | | | | | | | NITRIC NITROGEN (N) POUNDS PER ACRE. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth in Feet.... | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Tot'l. |
| MAXIMUM. | | | | | | | | | | | | | | | | | | | | | | |
| Corn | 3 | 14.91 | 15.17 | 15.22 | 14.94 | 13.62 | 15.65 | 14.60 | 13.46 | 11.17 | 12.61 | 7.7 | 3.8 | 3.8 | 6.2 | 9.3 | 3.8 | 7.1 | 11.4 | 7.6 | 12.8 | 73.5 |
| Potato | 5 | 15.14 | 13.7 | 13.42 | 13.21 | 13.00 | 12.54 | 13.24 | 13.02 | 13.03 | 12.94 | 5.5 | 5.1 | 4.0 | 3.7 | 1.9 | 2.5 | 4.5 | 3.1 | 2.6 | 2.7 | 35.6 |
| Alfalfa | 3 | 14.53 | 14.01 | 14.46 | 14.56 | 13.65 | 14.67 | 13.74 | 12.85 | 12.68 | 13.28 | 7.1 | 2.8 | 2.7 | 2.1 | 6.7 | 1.9 | 1.5 | 1.5 | 1.8 | 1.8 | 29.9 |
| Fallow | | | | | | | | | | | | | | | | | | | | | | |
| MEDIUM. | | | | | | | | | | | | | | | | | | | | | | |
| Corn | 5 | 14.76 | 11.82 | 11.11 | 10.97 | 12.14 | 12.94 | 12.80 | 12.04 | 10.63 | 9.46 | 5.5 | 3.0 | 2.6 | 2.8 | 2.5 | 5.9 | 9.9 | 8.6 | 4.6 | 3.0 | 48.4 |
| Potato | 5 | 13.24 | 12.37 | 12.10 | 12.08 | 12.09 | 11.94 | 11.08 | 11.31 | 12.8 | 12.07 | 3.1 | 2.9 | 1.9 | 2.2 | 17.8 | 6.2 | 6.9 | 5.1 | 5.5 | 3.2 | 54.8 |
| Alfalfa | 4 | 13.25 | 13.10 | 13.38 | 13.66 | 13.30 | 13.37 | 13.78 | 11.68 | 10.52 | 10.95 | 1.9 | 1.0 | 0.9 | 1.8 | 9.1 | 1.0 | 0.8 | 0.8 | 0.9 | 0.9 | 19.1 |
| Fallow | 42 | 12.89 | 13.38 | 14.22 | 13.83 | 13.92 | 12.11 | 10.06 | 10.18 | 10.54 | 11.23 | 14.6 | 17.6 | 12.6 | 26.9 | 19.1 | 9.9 | 7.4 | 8.1 | 18.6 | 7.5 | 142.3 |
| MINIMUM. | | | | | | | | | | | | | | | | | | | | | | |
| Corn | 4 | 15.28 | 13.84 | 13.78 | 13.11 | 11.58 | 13.83 | 13.31 | 12.39 | 11.72 | 10.27 | 6.2 | 4.4 | 8.7 | 11.5 | 5.7 | 8.0 | 5.8 | 3.7 | 2.8 | 3.0 | 59.8 |
| Potato | 4 | 12.99 | 11.47 | 12.27 | 12.9 | 12.35 | 12.71 | 11.74 | 10.88 | 12.69 | 11.75 | 12.8 | 9.0 | 5.3 | 5.1 | 5.7 | 9.9 | 6.7 | 5.7 | 3.4 | 3.7 | 67.3 |
| Alfalfa | 4 | 11.93 | 11.66 | 12.16 | 11.63 | 11.29 | 10.51 | 10.07 | 12.18 | 9.90 | 10.54 | 2.2 | 2.2 | 1.3 | 1.1 | 1.3 | 0.9 | 1.0 | 1.3 | 1.0 | 3.6 | 15.9 |
| Fallow | | | | | | | | | | | | | | | | | | | | | | |
| NONE. | | | | | | | | | | | | | | | | | | | | | | |
| Corn | 1 | 11.7 | 7.88 | 7.44 | 6.78 | 2.84 | 9.70 | 9.70 | 10.08 | 8.48 | 11.00 | 9.0 | 28.5 | 6.4 | 10.7 | 9.1 | 6.0 | 4.6 | 3.1 | 1.5 | 3.5 | 73.4 |
| Potato | 4 | 11.17 | 8.34 | 8.16 | 8.17 | 6.95 | 8.35 | 7.46 | 9.73 | 10.53 | 12.10 | 25.5 | 23.4 | 5.5 | 6.0 | 12.6 | 4.8 | 35.9 | 7.7 | 5.0 | 4.4 | 130.8 |
| Alfalfa | 4 | 8.4 | 7.48 | 7.54 | 6.96 | 6.14 | 5.58 | 6.36 | 7.52 | 5.69 | 5.82 | 3.5 | 2.1 | 1.9 | 1.7 | 1.2 | 1.2 | 1.3 | 1.3 | 4.4 | 8.3 | 26.9 |
| Fallow | 27 | 9.55 | 10.49 | 11.26 | 11.36 | 11.62 | 12.10 | 10.36 | 9.12 | 8.70 | 10.39 | 21.6 | 14.1 | 7.8 | 8.1 | 10.4 | 10.0 | 11.7 | 11.2 | 9.8 | 10.4 | 115.1 |

### c. Conclusion.

No definite conclusions can be drawn from the data given in this bulletin. Some very interesting facts have been brought out, and, although not conclusive in their nature, they offer suggestive material for thought and point out more clearly the lines along which investigations must be carried on in the future.

Our investigations seem to point to the existence of nitrate accumulations in the lower foot sections during the winter and spring. The existence of these "nitrate belts" points conclusively to the necessity of taking our samples to at least a depth of eight feet; and suggests a way in which irrigating water does affect the nitrates of the soil. If the rains of winter and spring dissolve out the soluble nitrates of the surface feet and carry them to greater depths it is evident that irrigating water would have the same effect. If irrigating water has this effect on the nitrates of the soil we have a probable explanation of the lower protein content of wheat grown on irrigated land as compared with that grown on non-irrigated or arid farm land in the West. The application of the irrigating water carries the nitric nitrogen content beyond the reach of the roots of the plant to such an extent that the plant is unable to obtain the necessary nitrogen for building a high protein content. In a non-irrigated soil, although the nitrate content would also be washed to a great depth by the winter and spring rains and there be deposited in accumulations, these accumulations would gradually rise to the surface during the growing season and thus become available to the plant, while on irrigated soil the constant application of irrigating water would tend to prevent the nitrates from rising to the surface. A heavy application of irrigating water would be more effective in this respect than a light application. In accordance with this it has already been shown that the per cent of protein increases very markedly in the wheat kernel as the amount of water applied to the soil decreases.

The low concentration of nitric nitrogen in the soil on which alfalfa was growing is an important fact brought out by these investigations. This is noteworthy in view of the fact that alfalfa is a leguminous plant and that all leguminous plants are supposed to obtain their nitrogen supply from nitrogen of the air. Throughout the season of 1906 the nitrate content of alfalfa land was usually below two parts per millian, thus showing a remarkably low content. It has already been demonstrated by Hopkins that the alfalfa plant first obtains its supply of nitrogen from the soil, provided the nitrogen of the soil is available; and secondly, from the atmospheric nitrogen. Our results are fully in accord with this.

We found that the fallow plot which received cultivation had a greater concentration of nitric nitrogen at the end of the irrigation season than did the fallow plot which was not cultivated. In the fall, however, a very interesting fact appeared; the nitric nitrogen in the cultivated and uncultivated plots was about equal. It would thus appear that the effect of cultivation on the nitric nitrogen content of the soil is only temporary. The greater amount found in the cultivated plots disappeared later in the season. If this be true, would it not appear that the cultivated plots were really poorer in nitrogen at the end of the year for having been cultivated?

The average amount of nitric nitrogen at the close of the spring period for the three years, in soil on which corn was growing, was 142 pounds per acre; on potato land there was an average of 98 pounds per acre; on alfalfa land there was an average of 27 pounds per acre; while on the fallow land the average was 165 pounds per acre. During the irrigating period, both before and after irrigation, we got results that were exactly in the same order. In the corn land the average before irrigation was 144 pounds per acre, while after irrigation it was 104 pounds per acre; in potato land the average before irrigation was 110 pounds per acre, while after irrigation it was 94 pounds. In the alfalfa land before irrigation the average was 34 pounds, while after irrigation it was 38 pounds; in the fallow plots the average was 174 pounds before irrigation, and 130 pounds after irrigation. During the fall period we have the same result; in the corn land there were 63 pounds per acre; in the alfalfa land there were 32 pounds per acre; while in the fallow land there were 151 pounds per acre.

Another noteworthy fact brought out in the study of the tables is that although the average nitric nitrogen content in alfalfa land was almost constant throughout the year it was slightly lower during the spring period. In the nitric nitrogen content in the potato and corn land, however, there was a steady decrease from period to period throughout the year. Again, the nitric nitrogen content in the fallow land remained nearly constant throughout the year. What is the explanation of the steady loss in potato and corn land? It can not all be ascribed to the plant factor, inasmuch as the loss continues after the growing period has ceased. It cannot be ascribed to cultivation, since the fallow plots were also cultivated.

A marked fact brought out in the study of the nitric nitrogen of the soil on which oats were growing during the two years' work was that the nitric nitrogen disappeared rapidly during the last few weeks of its growth.

The nature of the season apparently has a marked effect on the results obtained. In 1905 the application of irrigating water caused a decrease in the nitric nitrogen content of soil on which potatoes were growing, while in 1906 exactly the opposite was true, there being an increase in every case.

The work of this bulletin has shown clearly that, in order to obtain conclusive results, work must be planned so as to extend over a number of years, and in such a way, if possible, as to eliminate the plant factor. The effect of cultivation on the production of nitric nitrogen must be studied, not in detail, but in a general way. It also seems absolutely necessary to make an analysis of the various crops for the nitric nitrogen content, in order to follow the movement of the nitric nitrogen within the plant.

### 1. Summary of Conclusions.

1—The nitric nitrogen tends to accumulate in the lower foot sections during winter and spring.

2—The concentration of nitric nitrogen on alfalfa land is low

3—Cultivation seems to increase the nitric nitrogen content, but the effect does not seem to be permanent.

4—The different plants show a marked difference in their demands upon the nitric nitrogen of the soil.

5—There is a steady decrease in the concentration of the nitric nitrogen content of potato and corn land from period to period, while that of the alfalfa and fallow land remains nearly constant.

6—The nitric nitrogen of oat land disappears rapidly during the last few weeks of the growth of the plant.

7—The nature of the season evidently has a marked influence on nitrification.